8-23-2015

# Research on the application of solar photovoltaic system on large ocean-going ships

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# Research on the Application of Solar Photovoltaic System on Large Ocean-going Ships

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A research paper submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

**MASTER OF SCIENCE**

**(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)**

**2015**

## DECLARATION

I certify that all the materials in this research paper that are not my own work have been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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## ACKNOWLEDGEMENTS

I am sincerely grateful to World Maritime University for offering me this opportunity to study in the program of Maritime Safety and Environmental Management at Dalian Maritime University, China. My heartfelt gratitude also goes to Yantai MSA for supporting me to pursue postgraduate studies, as well as all the professors and staff in this program for their great teaching.

I would like to express my sincere appreciation to my supervisor, Professor Cheng Dong for his continuous guidance and generous support to my research work. I also would like to say thanks to all my kind-hearted classmates in the course of MSEM for their help in the whole year.

Last but not least, I would like to dedicate this research paper to my beloved little daughter who just got born at the beginning of this course.

## ABSTRACT

Title: **Research on the Application of Solar Photovoltaic System on Large Ocean-going Ships**

Degree**: MSc**

Under the situation of the growing shortage of global petrochemical energy and the increasingly stringent environmental protection requirements of IMO, further energy-saving and emission reduction on shipping industry become more imminent. The shortage of energy and the deterioration of the environment promote the development of new energy. However, among the 5 new energies (water energy, wind energy, ocean energy, geothermal energy and solar energy), solar energy is the most potential one to develop. It is a kind of inexhaustible, clean and renewable energy. The idea of applying solar power generation technology to ships has been proposed 50 years ago, but the technology is seldom used on large ocean-going ships. However, with the development of science and technology, the reduction of cost and the improvement of the conversion efficiency of solar cells, solar energy ship will have a good development prospect and will become one research focus on green ships in the future. Solar photovoltaic (PV) generation technology, with many advantages compared with other solar power generation form, gets increasing attention to be applied on board ships. Thus the application of PV generation on board ships will have a wide and far-reaching significance both on small tourism ships and on large ocean-going ships. In this paper, the following aspects of research are made on the application of PV generation on large ocean going ships:

- Introduction to the solar PV generation technology
- Application status of solar PV generation technology on board ships
- Key technologies of applying PV system to large ocean-going ships

- Restrictive factors and innovative solutions of applying PV system to large ocean-going ships
- Corresponding administrational countermeasures on application of PV system to large ocean-going ships

**Keywords:** Solar Photovoltaic System; large ocean-going ships; hydrogen fuel cells; administrational countermeasures; folding solar panel; solar energy ships.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AC | Alternating Current |
| CSIC | China Shipping Industry Corporation |
| DC | Direct Current |
| EEDI | Energy Efficiency Design Index |
| EEOI | Energy Efficiency Operational Index |
| FSCO | Flag State Control Officer |
| IEC | International Electrical Commission |
| IMO | International Maritime Organization |
| MSA | Maritime Safety Administration |
| MEPC | Marine Environment Protection Committee |
| NBTS | National Bureau of Technical Supervision |
| PSCO | Port State Control Officer |
| PV | Photovoltaic |
| UNESCO | United Nations Educational Scientific and Culture Organization |

# CHAPTER 1

# INTRODUCTION

## 1.1 Research background

### 1.1.1 Shortage of conventional energy

Nowadays the main energy used by human beings is petrochemical energy, such as petroleum, natural gas and coal. With the rapid development of modernization, the global energy consumption has doubled in the past 30 years. Energy crisis becomes increasingly imminent.(Bimal K. Bose, 2000). According to the comprehensive estimate for petroleum reserves, the maximum amount of petroleum reserves disposable is about 118 to 151 billion tons and will go up in 2040. Natural gas reserves are estimated at 131800--152900 trillion cubic meters. With the output of 2300 trillion cubic meters each year, it will be depleted within 57 years. Coal reserves are about 560 billion tons and can last for 169 years. (Zhang Liang, 2004) *Report of China Fuel Oil Market in 2012* pointed out that fuel oil consumption of transportation industry accounted for 39.87% of the total fuel consumption in China in 2012. The total consumption of marine fuel oil is about 18.34 million tons, which is roughly equivalent to the total fuel oil consumption of China's transportation industry. One research from the advisory council on global change in German shows that, in order to realize the sustainable development of global energy, the proportion of renewable energy should be increased from 20% in 2020 to 50% in

2050. (Grassi. H & Luther. J, 2004) Being recognized as the most ideal alternative energy internationally, solar energy is the most abundant renewable energy and is the source of all petrochemical energy as well as other renewable energy. As shown in Table 1.1.1, according to the forecast of international authorities, the proportion of global solar energy utilization will account for 13% -15% of total global energy structure in 2050.

Table 1.1.1—the forecast of proportion of renewable energy and solar energy in the energy structure by percentage

| Forecasted by | Energy | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Japan | Renewable energy | 20.2 | 23.5 | 33.6 | 42.7 | 53.4 |
| | Solar energy | | | 1.9 | 7.9 | 13.5 |
| Shell | Renewable energy | 22.2 | 20.9 | 32.3 | 43.3 | 54.6 |
| | Solar energy | | | 2.6 | 8.4 | 14.9 |
| Average | Renewable energy | 21.2 | 22.2 | 23 | 43 | 54 |
| | Solar energy | | | 2.3 | 8.2 | 14.2 |

Source ：Lin Jie, Yuan Chengqing, Sun Yuwei, et al. (2011). Study on Degradation of Optical Properties of Shipping Solar Cell Cover Glass.

### 1.1.2 Requirement of environmental protection

The shipping gas emissions (CO2, NOx and SOx) accounted for about 3.3% of the total global emissions in 2007, among which CO2 emission accounted for 2.7% of total global CO2 emission. A study by the United Nations in 2008 shows that the total carbon emission of the shipping industry is nearly 3 times as previously estimated. The annual carbon dioxide emission from tanker vessels and bulk carriers equal the emissions from the whole USA. Marine industry has major responsibilities for the Greenhouse effect and measures against profuse pollution should be taken. (Papalambopoulos Michail & Glykas Alexandros, 2008) Although the emission percentage of the seaborne trade is not huge, however, it is estimated that the emission of carbon dioxide from the seaborne trade will increase 5 percent annually. (Yuan Chengqing & Dong Congling, 2010)

According to statistics, carbon dioxide emission of global shipping industry is about 1.12 billion tons per year, which accounts for about 4.5% of global carbon dioxide emission, and the figure is expected to increase to 5% in 2050. The Spanish newspaper Rebellion pointed out that by 2020 the emissions of marine pollutants will increase by 75%.

Currently, transportation as well as its greenhouse gas emissions has become the central issue of the discussion about climate change. Although all the stakeholders relevant are subject to reduce carbon emission, the impact of international shipping industry is particularly striking. It is because, on the one hand, international shipping is not involved in the *United Nations Framework Convention on climate change*. On the other hand, based on this convention, IMO has carried out multi-party negotiations to implement increasing stringent environmental protection regulations. Reducing and controlling ship's emissions has become the consensus of the whole society, IMO will formulate and promulgate more stringent mandatory regulations on ship's emissions. **(**Lin Shangjun, 2014, May 5)

Since the 47th session of the Marine Environment Protection Committee (MEPC) of IMO in 2001, the reduction of the ship's greenhouse gas emissions has been put on the agenda. At the 59th session of MEPC in July 2009, IMO approved the *Provisional Guidelines for Calculation of New Ship Energy Efficiency Design Index* (EEDI), *Provisional Guidelines for the Voluntary Verification of New Ship Energy Efficiency Design Index* and *Guidelines for Voluntary Use of Ship Energy Efficiency Operational Index* (EEOI). In 2011, on the sixty-second session of MEPC, a new amendment was made on the *International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocols of 1978 and 1997* (MARPOL 73/78) which added Chapter 4 on ship energy efficiency and was put into force on 1 January 2013. The 65th session was hold in May 2013; it focused on air pollution, energy efficiency, greenhouse gas emission reduction and the consideration of mandatory documents. Under the framework of Article 4, MARPOL Annex VI, the mechanism of sulfur oxide emission was discussed.

Under the pressure of environmental protection requirements, international shipping enterprises are strengthening the research and investment on ship's energy-saving and emission reduction technologies. Thus application of clean energy on board ships has broad prospects and a better future.

## 1.2 Characteristics of solar energy

### 1.2.1 Advantages of solar energy

Among the 5 new energies (water energy, wind energy, ocean energy, geothermal energy and solar energy), solar energy is the most potential one to develop. It is a kind of inexhaustible, clean and renewable energy. (Li & Chen, 2011; Jia & Zhang, 2012; Wei & Luo, 2013).

In recent decades, with the development of science and technology, solar energy with its related industries has become one of the fastest developing industries in the world. Because it has the following characteristics (Yuan & Zhao, 2010):

a) Huge amount: The amount of the solar radiation energy that reached to the earth and used by human beings each year is equivalent to the energy emitted by an atomic bomb. A report from Japan Solar Generation Association shows that solar energy reaching to the earth is about 1 $kW/m^2$. If all of them can be converted into the energy consumed, one hour of sunlight illumination can provide all energy the word used for a whole year.

b) Endless supply: Calculated with the present power rate of sun, solar energy can be used for 10 billion years.

c) Easy to get: As long as there is sunlight, there is solar energy. No need to transport and extract.

d) Clean and pollution free: solar energy is one kind of “zero emission” energy, there is no pollutants emission during all stage of energy utilization.

### 1.2.2 Disadvantages of solar energy

Solar energy also has some shortcomings which have restricted its development and application.

a) Low energy density: Although there is abundant solar energy, the energy in unit area is low. The average solar energy density reached to the earth surface is about 1 $kW/m^2$. However, take the conversion efficiency of device into account, the energy being used in the end will become less.

b) Instability: Due to the alternation of day and night, change of weather condition and difference of geographic environment, the radiation of sun is unstable, which causes fluctuation of solar energy.

## 1.3 Main content

This paper is mainly about the research on applying solar photovoltaic generation technology to ships, points out the technical and legal factors that restrict the application of solar PV system on large ocean-going ships, and puts forward the control of photovoltaic power generation in large ocean going ships used the technical and regulatory factors, and puts forward some innovative solutions. Specific contents are as follows:

(1) Introduction to the solar PV generation technology

(2) Application status of solar PV generation technology on board ships

(3) Key technologies of applying PV system to large ocean-going ships

(4) Restrictive factors and innovative solutions of applying PV system to large ocean-going ships

(5) Corresponding administrational countermeasures on application of PV system on large ocean-going ships.

**CHAPTER 2**

# THE SOLAR PHOTOVOLTAIC SYSTEM

## 2.1 The principle of solar photovoltaic generation

Solar PV generation is based on the “photovoltaic effect” of solar cells. It is a kind of power generation form which transforms solar radiation energy (including direct radiation, scattered radiation and reflection radiation) into electricity directly. The “photovoltaic effect” is an effect that, when an object is subject to illumination, the electromotive force and current are generated due to the change of the distribution of electric charges in the object. Figure 2.1 shows the principle of photovoltaic generation. A part of photons incident into the semiconductor have specific energy. When the sun light exposure to the photovoltaic cell surface, the interaction between these photons and the material of semiconductor can produce negatively charged electrons and positively charged holes. If there is a PN junction in a semiconductor, the electrons spread to the N type semiconductor while the holes are diffused to the P type. The negative charges and the positive charges are gathered at the two ends of the semiconductor, and a voltage called photo-generated voltage is generated between the two sides of the PN junction. So if there is a wire connected with the two end of the PN junction, the charge flow can be charged, and the electric energy can be generated. This process is essentially the process of converting photon energy into electrical energy.

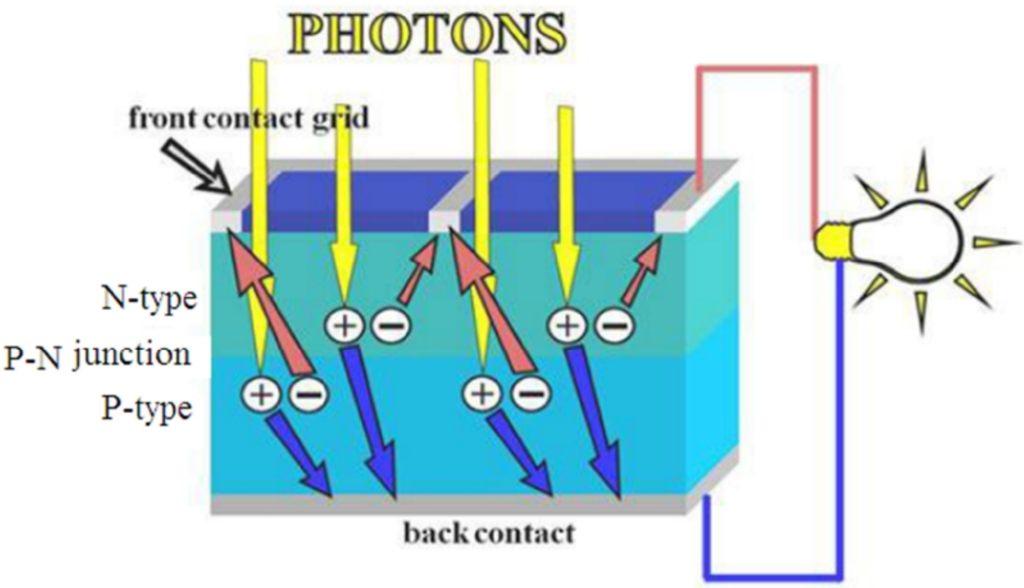


Figure 2.1—the principle of solar photovoltaic generation
Source: http://wenku.baidu.com/view/824c088ab8f67c1cfbd6b80c

### 2.2 The composition of solar photovoltaic power generation system

The solar PV system consists of five parts: solar cells, controller, battery or other energy storage equipment, inverter and load. According to its different applications, solar PV power generation system can be divided into the off grid photovoltaic system and the grid connected photovoltaic system. (Zhao Jianhua, 2004, PP. 82-83) Figure 2.2 introduces the composition of a typical photovoltaic system.

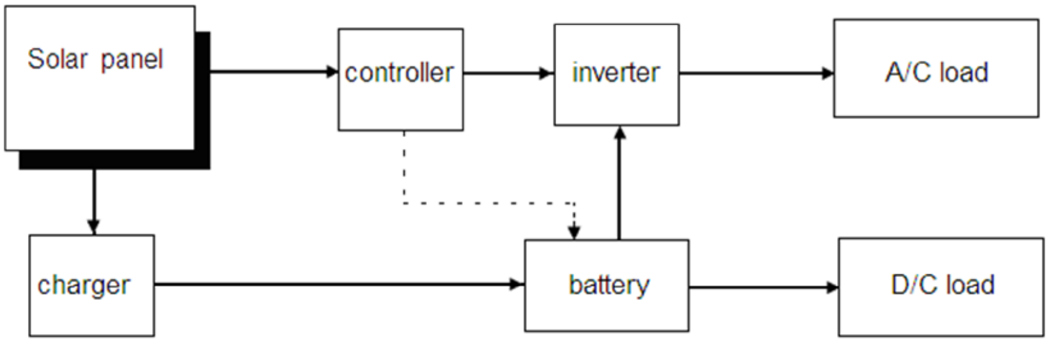


Figure 2.2—the composition of a typical photovoltaic system
Source: Author

### 2.2.1 Solar cells

Solar cells are the core parts of PV system, whose role is to convert solar energy into electrical energy for the AC load to use directly or to be stored in the storage battery. Solar cell is the smallest unit of photoelectric conversion. The size of a solar cell is generally 4~100 $cm^2$, the working current is about 20-25 $MA/cm^2$ and the working voltage is about 0.45~0.5 V which is far below the required voltage and current in practical application. Therefore, in order to meet the needs of practical application, PV Cells are wire in series to increase voltage and in parallel to increase current. A combination of solar cells is called solar module. A standard solar module consist of 36 or 40 solar cells (10 cm×10 cm), that is to say, a standard module can produce a voltage of about 16 V, which can charge a battery with a rated voltage of 12 V. (Zahdel A, 1998) Several modules form a solar panel and a number of solar panels form a solar array.

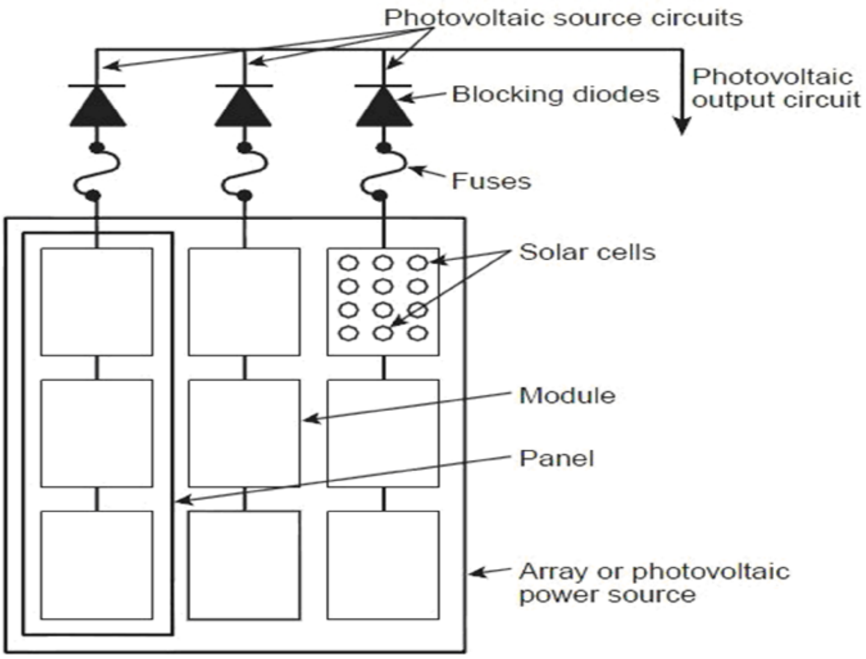


Figure 2.2.1—the composition of solar PV arrays
Source ：http://wenku.baidu.com/view/0c4753086c85ec3a87c2c579

### 2.2.2 Controller

Controller is a device for controlling and managing the solar PV system. For large and medium sized PV systems, functions of the controller are as follows.

a) Signal detection: The controller can detect the status and parameters of the various devices and units of the PV system, and provide the basis for judging, controlling and protecting the system.

b) Optimal charge control for battery: According to the situation of illumination and state of battery storage, the controller can determined the best charging method to charge fast and efficient.

c) Discharge control: The controller can manage the discharge process of the battery, such as automatic switch on and off, soft start, error protection prevention caused by connecting loads.

d) Equipment protection: In some cases, the electrical equipment connected to PV system need protection provided by the controller. For example, in the case of overvoltage or short-circuit, the PV system or devices could be damaged without the controller.

e) Fault location: The controller can detect the fault type automatically, indicate the location of the fault and provide reference for maintenance when the PV system breaks down.

f) Running status indicator: The controller can indicate the running status and the failure information of the PV system by the indicator light or the monitor.

### 2.2.3 Inverter

Inverter is a device which can convert DC into AC. As the current generated by solar cells or released from batteries are direct current, the inverter is indispensable if the load is an AC load. Inverter can be divided into off grid inverter and grid connected inverter by operational mode. Off grid inverter is used on off grid PV system which provides electricity for stand-alone load. Grid connected inverter is used on grid connected PV system which fed the electricity into grid

### 2.2.4 Battery

The role of the battery is to store the direct current which generated by solar PV arrays, and supply power to load at any time. In the solar PV system, the battery is in a state of floating charge and discharge. Under the condition of strong sun illumination, the PV arrays will supply electricity to the load and will also charge the battery. However, when the sun illumination is insufficient the battery will release the energy gradually.

a) electromotive force of battery

Electromotive force is the measurement of the theory output energy of the battery. Generally speaking, the higher the electric potential is the higher output energy the battery has, and correspondingly has a higher value. In theory, the electromotive force of the battery is equal to the electric potential difference of the two electrodes. In order to obtain a high value of electromotive force, the active substances are used on both the positive and negative electrodes.

b) Battery capacity

The quantity of electricity the battery released under a certain condition is called the battery capacity. It is the sum of the battery power and its commonly used unit is ampere hours (A·h).

c) Power of battery and weight-to-power ratios of battery

Battery power is the amount of energy the battery released in a unit time. Its unit is Watt. (W). (Sun Yuwei, 2010) The amount of power the battery can release by a unit weight is called weight-to-power ratios of battery. Its unit is W/kg. It is an important performance index of the battery, the greater the value is the bigger current the battery can release.

## 2.3 Classification of PV system

According to whether the electricity is fed into the power grid, solar PV system is divided into off grid PV system and grid connected PV system. (Dong Mi, 2007)

### 2.3.1 Off grid PV system

Figure 2.3.1 shows the component of off grid PV system. It consists of solar arrays, battery, controller and inverter. Solar panel is the core part of the system whose role is to convert solar energy into electric energy of direct current form. During daytime with sunlight, if the amount of electricity generated by solar arrays is higher than that of electricity needed by load, solar arrays can charge the battery as soon as supply electricity to load. When the sunlight is insufficient solar arrays and the battery can supply electricity together to load and only the battery supply electricity during night when there is no light.

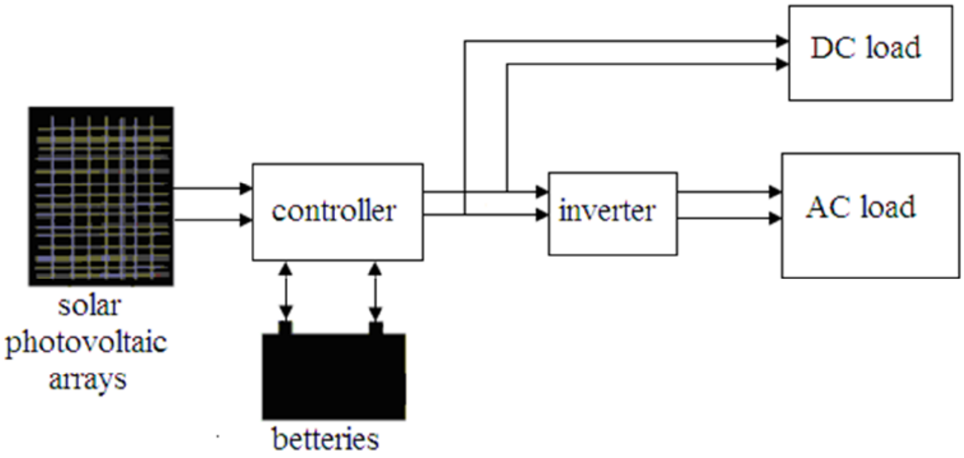


Figure 2.3.1—off grid PV system
Source ：Author

**2.3.2 Grid connected PV system**

Figure 2.3.2 shows the component of grid connected PV system. The PV system is connected with the power grid in the grid connected PV system, in which the inverter plays an important role in converting DC into AC. Based on whether there are batteries installed at the energy storage device in the system, the grid connected PV system can be divided into two kinds. The kind with batteries installed in the system is called adjustable grid connected PV system. The inverter in this system is equipped with main switch and switch of important loads, which makes the system own the function of uninterrupted power supply. (Liu Rong, 2000) Besides, this system can play the role of power regulator; it can stabilize the grid voltage, offset the harmful higher harmonic and improve the quality of the electric energy. Another kind without batteries in the system is called non-adjustable grid connected PV system, in which the inverter converts the DC generated by solar arrays into AC that has the same frequency and phase with grid current. The system would stop power supply when the main grid cuts the power. When the amount of electric energy generated is higher than that needed by the load under sufficient sunlight illumination, the excess portion of electric energy will be sent to the power grid. While the amount of electric energy generated is lower than that needed by the load with insufficient sunlight, the grid will supply power to the load automatically.

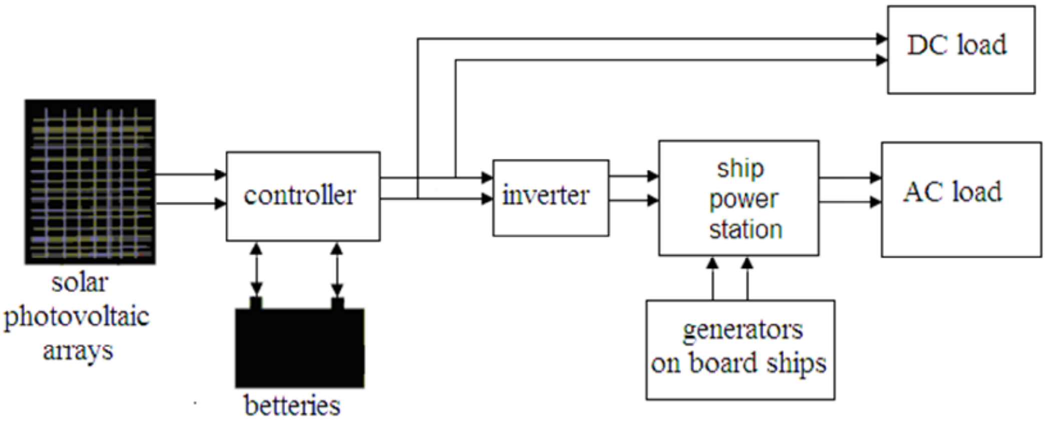


Figure 2.3.2—grid-connected PV system (with batteries)
Source: Author

## 2.4 Development of solar PV generation technology

Research for PV generation technology started about 100 years ago. In 1839, French physicist Becqurel found that potential difference can be generated when the semiconductor material is exposed to light, he called this phenomenon “photovoltaic effect” In 1880, Fritts Charles developed a solar cell based on selenium. At the beginning, the solar energy conversion efficiency is very low while the production cost is especially high. Scientists in all countries are working on the improvement of efficiency and reducing the cost. In 1954, Bell Laboratory invented practical solar cell of monocrystalline silicon whose conversion efficiency is 6%. From then on, the practical photovoltaic generation technology by converting solar energy into electric energy is produced. From 1961 to 1972, silicon solar cells technology has not made significant progress. The focus of the research is to improve the ability to resist and reduce costs. Between 1972 and 1976, different monocrystalline silicon solar cells for space station were developed. In the middle of 1970s, the ultrathin monocrystalline silicon solar cell was invented. After 1980s the solar cells types and the application range grew dramatically, the market scale gradually increased at the speed of 30%-40% every year. (Haas & Reinhard, 1999) In 1990s the PV generation technology got a rapid development. Until 2010, the average annual growth rate of solar cells and components in the past 10 years has reached to 33% and the rate in last 5 years is 43%. In recent years the PV generation market is showing the following characteristics: The substitution function of solar energy photovoltaic power generation is greatly increased in the energy structure. The proportion of application of grid connected grid PV system has risen steeply and has become mainstream product in the PV generation market. According to statistics, till 2000 the production of solar cells applied in grid connected PV system has exceeded 50% of the word's output and become the most important area of the PV generation market. Besides, with the large-scale application and the cost reduction of this technology, as a new pattern of decentralized power supply, grid connected PV system will have a very broad application prospect. (M. Oliver & T. Jackson, 2001)

### 2.5 Current status of solar PV generation in China

On the one hand, in order to solve the electricity supply problems in remote villages, the PV generation technology in China are mainly applied to household's power generation and construction of small PV power station. 2 million farmers and herdsmen in remote areas which account for one third of people having no access to electricity have been provided with the most basic power supply.

On the other hand, by drawing on the experience of building rooftop photovoltaic generation system in developed countries, roof photovoltaic generation system and PV lighting system are constructed in roads, parks, railway stations and other public facilities in large urban and cities. (M. Oliver & T. Jackson, 1999) Besides, China government are planning to build large grid connected PV power station to make preparations for mass application after the cost of PV generation reduced.

# CHAPTER 3

# APPLICATION OF SOLAR PV GENERATION TECHNOLOGY ON BOARD SHIPS

## 3.1 Reasons of applying solar PV generation technology on board ships

The development and utilization of solar energy mainly include three kinds of forms: optothermal utilization, photochemical utilization and photovoltaic utilization. Optothermal utilization is to convert solar energy into heat energy and store them. The most successful application in this area is solar water heater. Another area for this technology is optothermal power generation. It is the use of collector to collect solar radiation energy to heat water and generate steam, the steam can be used to drive steam turbine and then drive generator. Photochemical utilization is still in the stage of experiment, such as the photochemical hydrogen production by decomposing water. However, the photovoltaic utilization can be applied on board ships because of the following advantages: (Cui Rongqiang & Xi Wenhua, 2004)

a) Simple structure, small size and lightweight. Both the module and array of the off grid PV system are relatively simple. For example, the volume of crystal silicon solar cell module with output of 45-50W is 450mm×985mm×45mm, and the quality is only 7kg.

b) Easy installation and short construction period. Take a 6.5mw solar power station for example, it covers an area of about 80 $km^2$ and can be put into production in less than 10 months.

c) Simple maintenance and easy to use. In case of bad weather, just check whether the surface of the panel is soiled, wiring is reliable or the battery voltage is normal. It can be controlled by computer, so the running cost is low.

d) Clean, safe and noise free. Photovoltaic power generation itself doesn’t discharge waste, has no mechanical noise and is an ideal energy.

e) High reliability, long life, and wide application. The life of crystalline silicon solar cells can be as long as 20-35 years. Besides, as long as the design of PV system is reasonable, the life of the battery can reach 10 years.

The demand for hot water is not very big during the process of ship’s running, and the thermoelectric conversion in the limited ship’s deck space is difficult to implement, so the possibility to apply optothermal utilization on board ships is not very high. In addition, in the present technology there is little possibility to apply the photochemical utilization on board ships neither. With the further development of solar photovoltaic technology, the efficiency `reliability and stability of the PV system have been greatly improved. The initial technology research has been gradually applied in the actual application domain. The application of solar photovoltaic generation on board ships is an important direction of the development of green ships. (Yan Xinping, 2010)

### 3.2 Application of solar PV generation technology on small ships

The idea of applying solar photovoltaic power on board ships has existed since 1980s. In 1985, a company named Smith Sun in Texas, USA launched a solar charging device called Systein-12, which can charge batteries for vehicles and ships. (Mao Yixin, 1986) Subsequently, the relevant enterprises and research institutions in many countries began to introduce small solar powered sample ships.

In 2000, the ferry “SOLAR SAILOR” was officially put into operation during the period of Sydney Olympic Games. The main scale of the ship is 21m×10m×1.3 m, with 2 sets of main propulsion motor and 8 solar wind panels. The maximum capacity is 100 people and maximum speed is up to 10kn.[1]


Figure 3.2 (a)—“SOLAR SAILOR”
Source : http://en.wikipedia.org/wiki/Solar_Sailor_Holdings

Swiss solar boat "SUN 21" set sail from Basel, Switzerland on October 16, 2006 and arrived in New York on May 8, 2007. It was the first ship across the Atlantic only relying on solar energy power in the world. The ship weighed 12 tons and is14 meters long. 60 $m^2$ solar panels were installed on the top of the ship and provided energy for the two main engines on the ship.

In 2010 the largest solar powered ship “PLANET SUN” was manufactured in Germany. It is 31m long, 15 meters wide and 60 tons weight and it can accommodate more than 50 people with the highest speed of 26 km per hour. The 500 $m^2$ solar panel can provide 12kw power and the full charged battery can keep the ship sailing 3 days without

1.The website gives further information: http://en.wikipedia.org/wiki/Solar_Sailor_Holdings sunlight.[2]

Figure 3.2 (b)—“PLANET SUN”
Source: http://baike.baidu.com/view/3296647.htm?fr=aladdin

In 2010 the first solar hybrid ship in China “Shang De Guo Sheng” started to provide services for sightseeing in Shanghai EXPO. The ship's scale is 31.85m×9.8m×7m and can accommodate 150 tourists. With 70 pieces of solar panels (20kw) and 2 sets of main generators (140kw) charging, the total capacity of the battery can reach to 180AH. (Zhang Yi & Guo Dong, 2012)

2.The web site gives further information: http://baike.baidu.com/view/3296647.htm?fr=aladdin


Figure 3.2 (c)—"Shang De Guo Sheng"
Source ：http://www.frponline.com.cn/special/3/112.html

### 3.3 Application of solar PV generation technology on large ships

The application of this technology mainly concentrates on small river ships, especially on small tourist boats, which require higher environmental protection. However, solar photovoltaic system as a combination of diesel engine generator is also used in large ocean-going ships. In 2008 Japan built a solar power ship called "Auriga Leader", with 328 solar battery array panels, the output of which is 40kw, that is 6.9% of lighting output or 0.3% of propulsion output. (He Shengqiang & Weixiao, 2008)

Figure 3.3 (a)—“AURIGA LEADER”
Source ：http://www.zgsyb.com/GB/Article/ShowArticle.asp?ArticleID=76266

In March 13, 2012, the world's first hybrid car ro-ro ship "EMERALD ACE" was launched in Japan merchantman Mitsui Group Shipyard. The ship is equipped with a set of grid connected PV system, including 160kW solar arrays and 2200kWh lithium batteries. The lithium batteries are located in the double bottom and used as ship’s ballast. During navigating, the PV system generates electric energy and stores them in the lithium batteries. When the ship stays in the port, all diesel generators are completely shut down and the batteries provide all the electricity required for the ship to achieve zero emissions of CO2.[3]

In March 22, 2014, 540 solar panels with 1050 $m^2$ were installed on “COSCO Teng Fei”. The maximum power of the battery is 143.1kw and can be fully charged in 5 hours. It can provide 700 KW·h of electricity in one sunny day that is equivalent to burning 0.38 tons of diesel oil and can save 200,000 dollars per year. (Lin Shangjun, 2014, May 5)

3. The web site gives further information: http://www.cn-dianchi.com/news/show-16782.html


Figure 3.3 (b)—"COSCO TENG FEI"
Source: http://www.coscol.com.cn/News/Detail.aspx?ID=9915

### 3.4 The significance of application of solar PV generation technology on board ships

A PV system with capacity of 1 KW can reduce the emission of CO2 600-2300 Kg ' NOx 16 kg 'SOx 9 kg and some other particles 0.6 kg. (Yang Jinhuan & Chen Zhonghua, 2001) Take the ro-ro ship "COSCO TENGFEI" for example, working in grid connected model, the system can produce 140 KW's electrical energy for the grid in daytime, which includes 35 KW for lighting and 105 KW for charging the batteries fully. At night, the batteries (650 KW.H) can provide electricity for the lighting for 12 hours. According to the calculation, the ship can save 0.6 tons of fuel per day and 220 tons per year. That means 200 thousand dollars per year. Besides, it can reduce emission of CO2 224043.9 kg 'SOx 4946.6kg and NOx 412.7kg. (Qiu Liqiang & Jiang Qizhen, 2014)

### 3.5 Summery

Compared to other solar energy utilization technology, solar photovoltaic generation is more suitable for application on board ships with its unique advantage. Currently this technology is already maturely used on small tourist boats but is still in experimental and the initial stage on large ocean-going ships. The application of solar photovoltaic generation on large ocean-going ships will be a trend and will make a great contribution to the ship energy-saving and emission reduction in the future.

# CHAPTER 4

# KEY TECHNOLOGIES OF APPLYING PV SYSTEM ON BOARD SHIPS

## 4.1 Selection of available ship type

Typically ocean-going ship includes the following six types: container ship, special ship, general cargo ship, ro-ro passenger ship, bulk carrier and large oil tanker. To install PV generation system on board requires enough space for the arrangement of PV arrays on or over the main deck of the ship. If the conversation efficient of the monocrystalline silicon solar cell is 13%, 10 square meters layout area of the solar arrays are needed to get average output power of 1 kW PV system. (M.F. AIHajri & K.M. EL-Naggar, 2012 ) Therefore, in order to get enough power, the ship must be required to provide a large enough area for the arrangement of solar arrays. The main deck and other locations of container ship, general cargo ship and special ship do not have the possibility to provide a large area for solar arrays. With large area on main deck, oil tanker is the most suitable type of ship for installing solar PV arrays. There is not so much deck machinery behind the bridge on top deck of ro-ro ships, large areas can be used to install solar PV array. Besides, the hatch covers of large bulk carriers are available, too. Most bulk carriers are flat on the deck and is conducive to the installation of solar arrays, except for some ships with cranes. Hence oil tankers, ro-ro ships and large bulk carriers are the ideal ship types for solar arrays installation.

### 4.2 Selection of solar cells material and de termination of PV module capacity

#### 4.2.1 The selection of material of solar cells

The most important part of a solar PV cells is the semiconductor material. The PV materials being researched and applied in the world mainly include monocrystalline silicon, polysilicon material and amorphous silicon material, among which the crystal silicon cells have about 80% of the market share while the amorphous silicon material accounts for more than 10% (Xiao, 2004, PP. 71-74) Based on the absorption efficiency of light, energy conversion efficiency, technical maturity and the manufacturing costs, each of the PV material has its own characteristics:

a) The monocrystalline silicon PV cell has the highest conversion efficiency, the most mature technology and the longest service life among the silicon PV cells. (Wu Yuzhi,2002) At present, the highest conversion efficiency of monocrystalline silicon PV material is 24.7% in the laboratory and 15% in the scale of production while the conversion efficiency of polysilicon PV cells can reach 10%. (Zhao, 2004) However, due to the high price of monocrystalline silicon material as well as the corresponding cumbersome solar cell technology, the cost of the monocrystalline silicon cells always stays high.

b) Amorphous silicon thin film solar cells are subject to people's attention and have been developing rapidly in recent years because of its rich resources, simple production process, low cost and scale production. However, compared with crystalline silicon solar cells, its conventional efficiency is low and stability is poor. (He & Zhang, 2002) According to the characteristics of marine environment, the amorphous silicon cells are not suitable for marine installation. (Tyagi, 2013)

c) Compared with monocrystalline silicon cells, polycrystalline silicon thin film solar cells have the following advantages: using less silicon material, free from efficiency recession, being made on cheap substrate material, low cost and higher conversation efficiency than amorphous silicon cells. Thus, the polysilicon film cells will soon dominate the market of solar PV cells in the future.

### 4.2.2 The determination capacity of solar PV module

The basis for determining the capacity of the solar PV module is to meet the annual demand of the load. The method of calculating solar cell components is to divide the energy generated by a solar cell component in a whole day by the average energy needed by the load each day. This method can calculate the number of solar modules that need to be paralleled, which can supply the current required by the load in the system. Besides, the number of solar modules working in series can be calculated through dividing the nominal voltage of one solar module by the nominal voltage of the system. The solar modules wired in series can provide the voltage that the load in the system required.

During the course of ship operation, due to the complex and changeable environment of sea, the surface of solar modules will be covered with the dust and salt, the performance of solar modules will degrade, which results in the lower output of the solar arrays. In the design process, excess solar module of 8% ~ 10% should be added in the system in order to ensure the safety of design (Zhang & Guo, 2012).

### 4.2.3 Summery

At the present photoelectric conversion efficiency, polysilicon thin film solar cells are the most suitable for large ocean-going ships. The extra 8% to 10% of solar module of 8% ~ 10% should be added in the PV system to ensure safety in the design process.

## 4.3 Way of solar arrays installation

There are mainly two ways to install solar arrays on board ships ：fixed installation and directional installation. (Wei & Luo, 2013)

### 4.3.1 Fixed installation

Fixed installation can be divided into fixed horizontal installation and fixe inclined installation. With simple structure and no additional equipment is needed, fixed horizontal installation is a reliable installation type for ships and airplanes but it receives a relatively low solar radiation. The advantage of fixed inclined installation is that the PV system has a better solar radiation value when the optional angle of inclination is installed. However, the ship is a mobile platform without the optional angle of inclination. Thus fixed inclined installation is not suitable for large ocean-going ships.

### 4.3.2 Directional installation

Directional installation means installing solar cells on solar trackers. The solar tracker can be divided into single axis tracker and biaxial tracker. Single axis tracker means fixing solar panel on one rotatable center axis. Based on the position of the sun, this design can achieve the target of racking the sun by rotating the center axis to change the angle between the PV panel and the horizontal plane. The ship is moving during running operation, thus single axis tracker is not suitable for installing on ships. Biaxial tracker refers to the solar panel rotates around two different central axes at a same time, making the solar panel being always vertical with sunlight and getting the maximum solar radiation. However, the reliability of the excess tracking device as well as the tracking control should be considered when the biaxial tracker is used on board ships. Besides, the following factors should also be considered: the extra power consumed by running the tracking device, the investment of the system, the follow-up maintenance of the device followed-up.

### 4.3.3 Summary

Considering the ship’s heeling and vibration during sailing, the impact of storm on the solar panel as well as the reliability and cost of device, large ocean-going ship should take the type of fixed horizontal installation as its first choice.

### 4.4 Arrangement of PV system

The arrangement of PV system contains the arrangement of arrays `batteries and cables. (Wu Xinxian, 2010) There are relevant regulations on the arrangement of batteries and cables, but there is no specification on the layout of solar arrays.

#### 4.4.1 Arrangement of solar arrays

There are many limiting factors in the arrangement of the solar arrays on limited ship deck. Practical power consumption should be considered firstly in off grid PV system while in grid connected PV system, maximizing the arrays' arrangement area is the first element to be considered. (Lin Jie & Yuan Chengqing, 2010) Normally, in order to get the maxium solar radiation and provide the maxim output, all the arrays should be arranged in the sun, all solar panels should avoid shading each other or being shaded by the superstructure and other deck machines. The physical space and the total area of the ship deck are very limited, so the area for arrangement should be as big as possible. However, at the same time, the cost and the ship operation safety should also be considered. Non-operational areas and special areas cannot be used for arranging solar arrays, such as the emergency helipad.

#### 4.4.2 Arrangement of batteries

The installation as well as the ventilation of the batteries should both be in accordance with the steel ship construction specification. As the charge and discharge of battery can release harmful gases, the battery room should be isolate completely with the accommodation and the engine room. The temperature in the battery room should be controlled between 10℃ to 30℃, and good illumination and ventilation are essential. In order to keep the capacity of batteries, the temperature should not less than 0℃, otherwise heating should be supplied. (Steel Ship Construction Specification 2004)

### 4.4.3 Arrangement of cables

In order to reduce the voltage loss, improve the output power of system, cut the cost of cable and increase the flexibility, the cables between solar module and inverter should be as short as possible.

### 4.4.4 Summary

Under the premise of ensuring the safety of the ship, the arrangement of the solar arrays on large ocean-going ships should be carried out in accordance with the principle of maximizing the arranging area and the efficiency of the arrays. The arrangement of batteries and cables can be implemented according to the S*teel Ship Construction Specification.*

## 4.5 The selection of the type of PV system

There are two kinds of PV system: the off grid PV system and the grid connected PV system. The selection of PV system type is decided by the following two factors: the amount of power energy the system provided and the environment of the ship, including its sailing routs, voyage and weather conditions.

### 4.5.1 The amount of power energy the system provided

Table 4.5.1—electrical load of “COSCO STAR”

| COSCO STAR | during voyage | leaving port | loading unloading | at anchorage |
|---|---|---|---|---|
| intermittent load/kw | 161.87 | 335.53 | 317.22 | 195.57 |
| sustained load/kw | 420.901 | 774.79 | 490.03 | 277.85 |
| maximum load/kw | 485.65 | 909.00 | 616.92 | 356.08 |
| generator N.O x power/kw | 1X560 | 2X560 | 2X560 | 1X560 |
| power of generator/kw | 560.00 | 1120.00 | 560.00 | 560.00 |
| power percentage of PV arrays/% | 33.2% | 17.6% | 25.92% | 43.8% |

Source ：Demonstrative Project of Solar Photovoltaic System on Ro-ro Passenger Ship “COSCO Star”

See table 4.5.1, take “COSCO STAR” for example, the ship was installed with a solar PV system of 16KW which can provide 33.2% of total power consumption during voyage and 43.8% at anchorage. The power the system provided has a significant impact on the total load of ship’s power station; therefore, the grid connected PV system is more suitable for the ship. Photovoltaic array provides only part demand of load for electricity power. If power supply is insufficient it will switch to main power station while power supply is sufficient the power surplus can be fed to the main grid and save large amounts of the electrical energy for the ship.

### 4.5.2 Sailing route, range of voyage and weather conditions

Ocean-going ships have long range of voyage with long time sailing and complex and changeable weather condition, they are not fit for off grid PV system. (Li Jin, 2010) For ships with short range voyage, fixed sailing routs, stable weather conditions and stable electricity power production of PV system, grid connected PV system would be a better choice. Off grid PV system is suitable for power supply with relatively stable load, such as ship's lighting. When system's power supply is insufficient it will switch to main power station. The design scheme of ship's off grid PV system is shown in Figure 4.5.2.

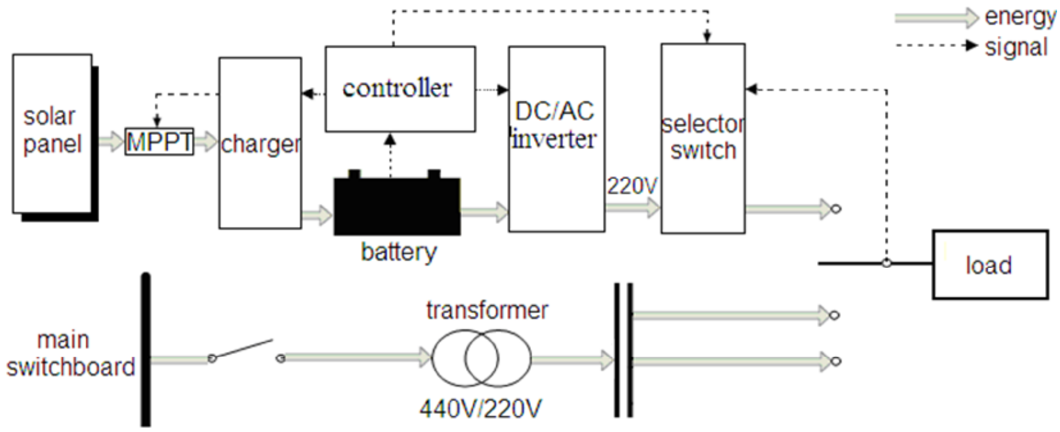


Figure 4.5.2—the application of off grid PV system on board ships
Source: Author

### 4.5.3 Summary

For ships with short range voyage, fixed sailing routs, stable weather conditions and stable electricity power production of PV system, grid connected PV system should be used. For the large ocean-going ships with long range voyage and large area of deck to install PV arrays, grid connected PV system is a better choice.

# CHAPTER5

# RESTRICTIVE FACTORS AND INNOVATIVE SOLUTIONS OF APPLYING PV SYSTEM ON LARGE OCEAN-GOING SHIPS

## 5.1 The arrangement of solar arrays on large ocean-going ships

At present, the conversion efficiency of solar PV cells is about 15%. (Zhao Jianhua, 2004) In order to apply solar PV generation technology to large ocean-going ships on a large scale, it is necessary to expand the laying area of PV arrays as big as possible. However, the effective area for the ship to lay the PV arrays is limited. According to statistics, the deck area of 90% of the global ocean-going bulk carriers is less smaller than 10,000 $m^2$. (Glykas A & Papaioannou G, 2010) Therefore, innovative method must be adopted to increase the laying area of the PV arrays.

### 5.1.1 Arrangement of PV system on large bulk carriers and large oil tankers

A kind of folding solar PV panel can be applied on large ocean-going ships as a satellite does. The system consists of folding solar panels, panel storage chamber and the guiding rails. In good weather, the solar arrays can be stretched and generate electricity during navigating or anchoring. In bad weather or during loading and unloading the panels will be folded and stored in the arrays storage chamber. This design will not only increase the electricity generating capacity but also make a very good protection on solar arrays when the cargo is handling in port. Besides, the arrays fixed on large oil tankers can cool oil tanks down after stretching under the sun light. Figure 5.1.1(a) shows how the system works.

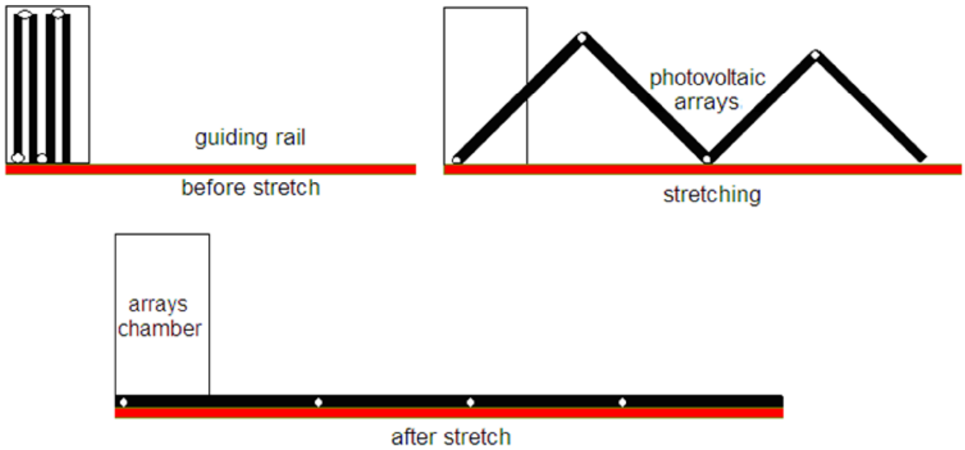


Figure 5.1.1 (a) — folding solar PV arrays
Source: Author

Large bulk carriers and oil tankers are similar; both have large area to install the solar arrays on the main deck. Take large bulk carrier for example, there are two installation positions for nearly all kinds of bulk carriers. The first position is over the hatch cover and the second position is at the gunwale where arrays storage chambers can be installed instead of the railings. In good weather, the folding panel can be opened and generate power during voyage. In bad weather or in the port, the arrays should be folded and stored in the storage chamber.

As in figure 5.1.1 (b), take a 76000WT bulk carrier for example, the ship is 222 meters long and 32 meters wide. The daily electricity consumption during voyage is 9060 kw·h. If both sides of the ship railings are installed with solar panels about 180m long and 15m wide. Adding the area of arrays on hath cover, the total area of the arrays will be 10000 $m^2$. The current efficiency of solar module is 162 $W/m^2$, if the sunshine hours can reach 6 hours per day, the total amount of electricity generated each day will be:

$$\mathbf{E=10000\ m^2 \times 162\ W/m^2 \times 6h = 9720\ kw \cdot h}$$

The PV system can provide 107.3% of the power consumption during the voyage of the ship.

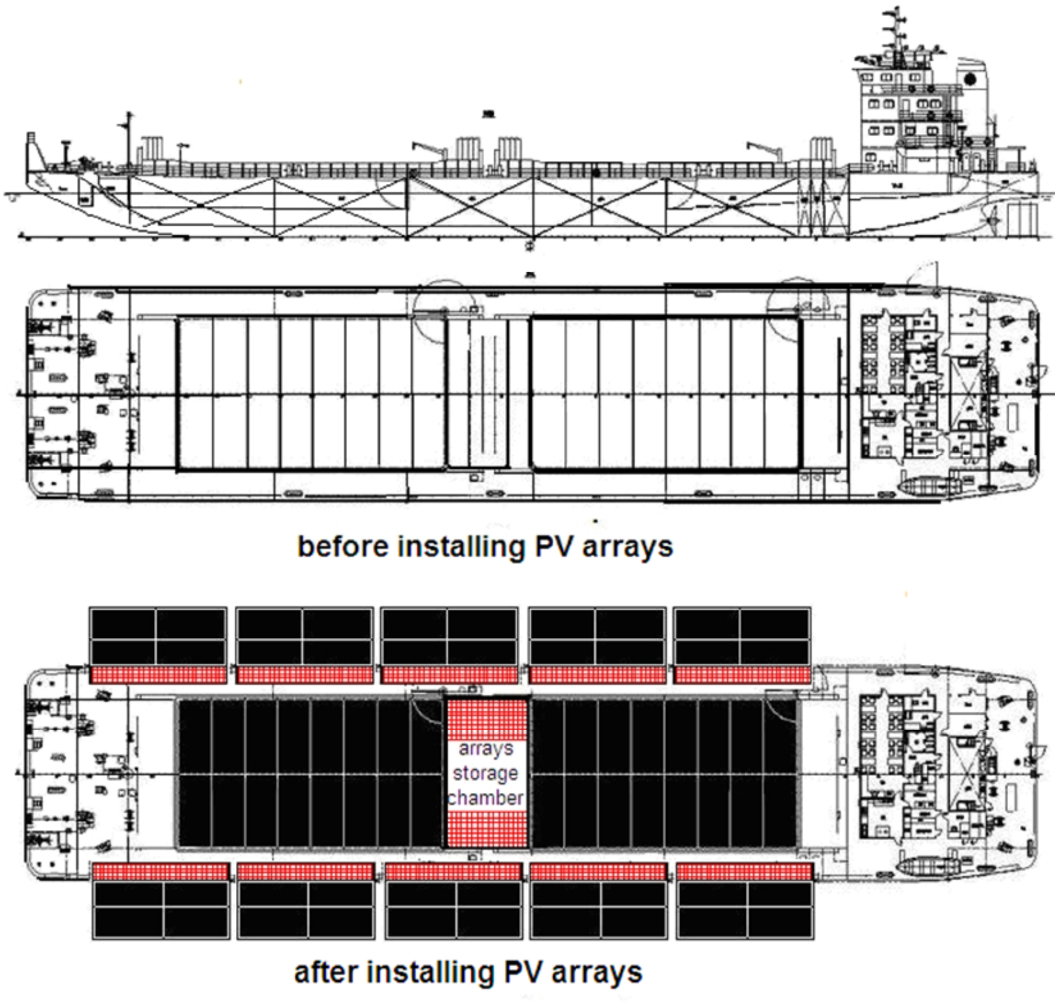


Figure 5.1.1 (b) — installing positions of solar PV arrays on large bulk carriers
Source: Author

### 5.1.2Arrangement of PV system on ro-ro and passenger ships

The common characteristic of large passenger and ro-ro ship is a high freeboard. Fixed horizontal arrays can be installed on the top deck. Besides, the hull of ro-ro ships can also be used to install some fixed vertical arrays. As in figure 5.1.2 (a) and figure 5.1.2 (b), take "COSCO STAR" for example, the ship is 186 meters long, 27.5 meters wide and 34 meters high. 3000 $m^2$ horizontal solar arrays can be installed on the top deck while 2500 $m^2$ vertical arrays can be installed on the hull of two sides of the ship.

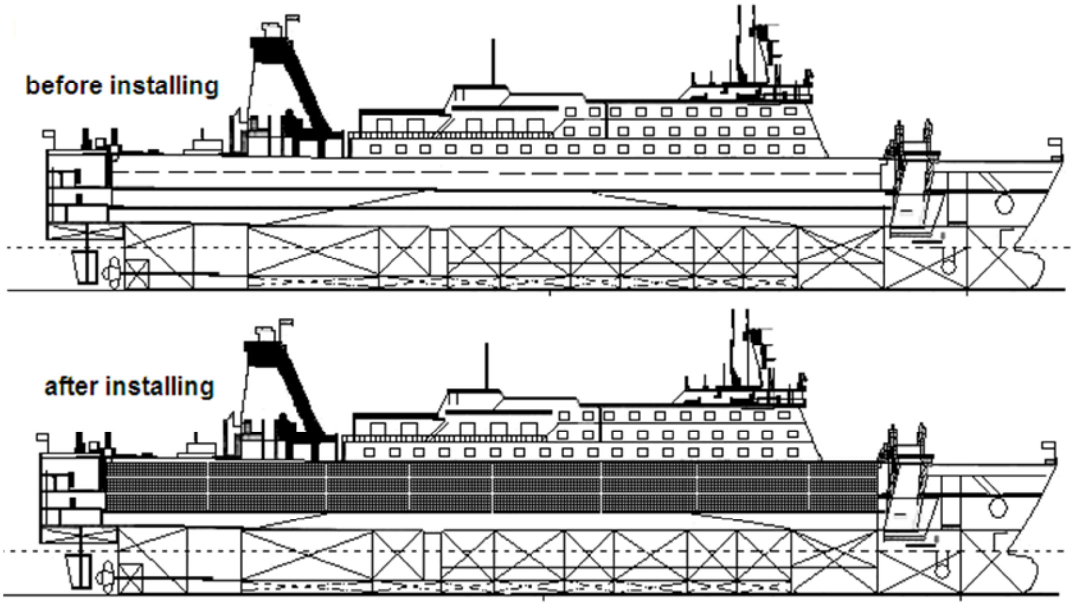


Figure 5.1.2 (a) — PV arrays installed on “COSCO STAR”
Source ：Author

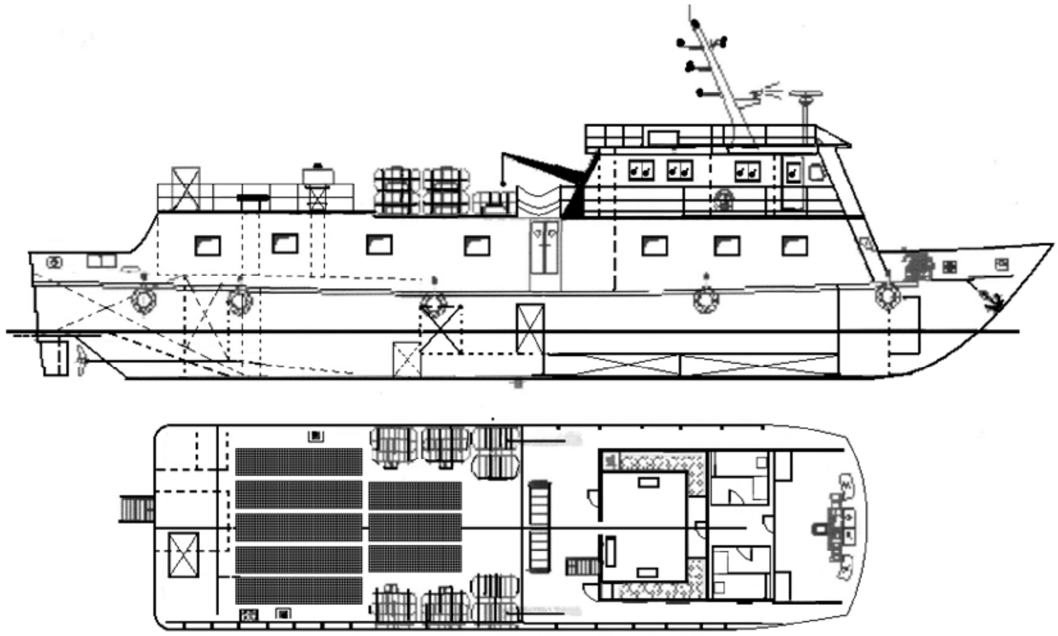

Figure 5.1.2 (b) — PV arrays installed on passenger ship
Source: Author

### 5.1.3 Summary

Installing folding solar arrays on large oil tankers as well as bulk carriers or applying fixed vertical arrays on the hull of ro-ro ships and passenger ships can greatly increase the mounting area of the solar arrays.

## 5.2 Method to avoid over electro-discharging of batteries

The amount of energy the PV system generated is closely related to the meteorological conditions. During the condition of continuous overcast or sustained severe weather, solar PV arrays can not generate electricity, which will cause the over electro-discharging of batteries. To avoid over electro- discharging of batteries, an external power source is needed to charge the batteries when the solar arrays are unable to generate electricity. Figure 5.2 shows how to solve this problem. When the battery reaches its limit and can not be charged by PV arrays, ship's power grid connected with charger can be used to charge the battery after the current is rectified by rectifier.

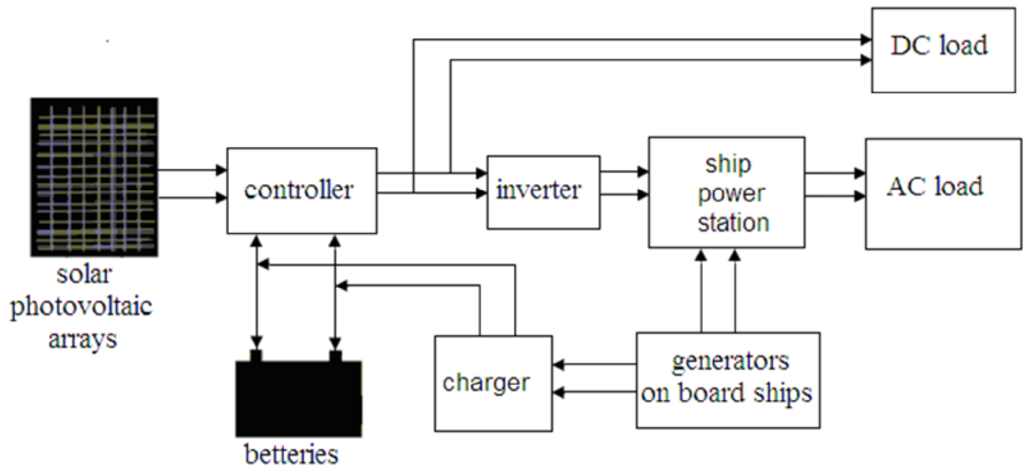


Figure 5.2—PV system with batteries charged by ship's power station
Source ：Author

### 5.3 Application of hydrogen fuel cell on large ocean-going ships

#### 5.3.1 Disadvantage of current batteries

The basic requirements for the battery in a solar PV system are as follows: low self-discharge rate ，long service life ，deep discharge ability ，high charging efficiency ， wide working temperature range and the load can still work normally with the battery under the situation that the time of the continuous sunlight exposure is short. Most of the energy storage device used in solar PV system nowadays is the ordinary lead-acid battery. But this kind of battery has small energy density, limited life and large weight. (Feng Hanzhang & Wang Dong, 2000) Some ships apply lithium batteries with higher weight-to-energy ratio as the energy storage device. For example, the ship "EMERALD ACE" was installed with 2200kW·h of lithium batteries in its ballast water tanks to store electrical energy. Compared with the ordinary lead-acid battery, lithium battery has a longer service life and higher energy density with 460-600W·h /kg which is 6-7 times higher than ordinary lead-acid battery's. (Li Fen & Chen Zhenghong, 2011) However, Lithium batteries are vulnerable to overheating if overcharged, or if discharged too rapidly, and overheated or damaged batteries can catch fire. (Zhang Yi & Guo Dong, 2012) Besides, lithium batteries have higher cost, shorter service life and large weight for ship's load.

### 5.3.2 The assumption of applying hydrogen fuel cell to large ocean-going ships

There are three kinds of energy storage devices: conventional lead-acid batteries, high performance battery (such as lithium ion battery) and fuel cell (such as hydrogen fuel cell), among which (hydrogen) fuel cell has a large capacity, high specific energy, extensive power range, low noise and is considered to be the most promising energy storage device in long distant. (Huang & Zhang, 2005) Hydrogen fuel cell is a kind of energy storage device which uses hydrogen as fuel, oxygen as the oxidant and generates current by chemical reactions. The hydrogen production and hydrogen storage technology is the key technology of using hydrogen fuel cell on ocean going ships. (Chen Lijian & Xu Jianyong, 2012) There are three kinds of methods to produce hydrogen with solar power: pyrolysis from water, direct decomposition of water, photovoltaic decomposition of water. Using solar photovoltaic panels as the energy receiving device makes it necessary to choose "photovoltaic decomposition of water" technology to produce hydrogen on ships. As shown in figure 5.3.2, hydrogen production and hydrogen storage devices play a role as a bridge between energy receiving devices and energy consuming device and overcome the limitations of low solar energy density and uncertainty of ship's time and location.

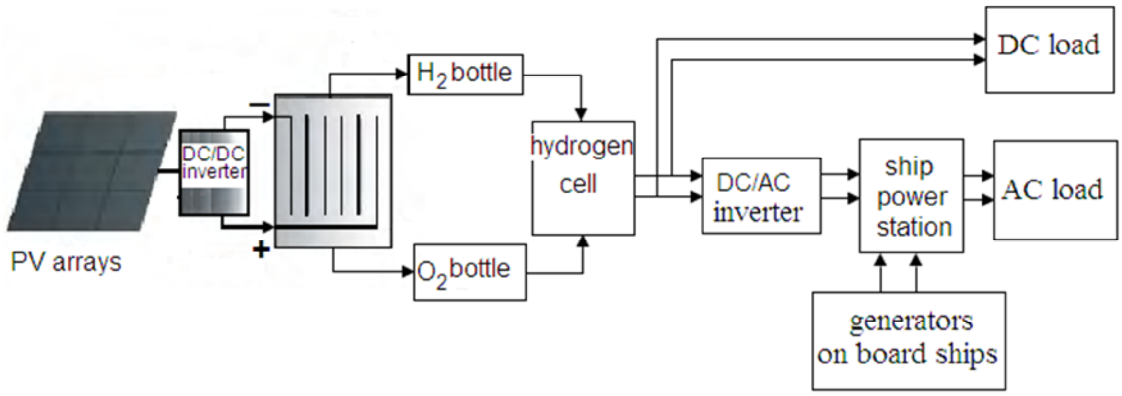


Figure 5.3.2— hydrogen fuel cell used on large ocean-going ships with PV system
Source ：Author

### 5.4 Improvement of the reliability of PV system in the marine environment

The core of application of PV technology is the PV conversion efficiency of semiconductor. (Zhang Hongmei & Yi Yunhua, 2008) In order to protect the semiconductor silicon of the solar cell, a glass cover is applied over the PV panel. (Koehl M, 2001) The conversion efficiency of a PV system depends not only on the PV conversion efficiency of the semiconductor material itself, but also on the spectral transmittance of the glass cover. The conversion efficiency of the PV system will inevitably decrease with the decrease of the spectral transmittance of its glass cover. (Zhao Liangliang & Yuan Chengqing, 2010)

The environment of marine solar panels is very rigorous which can provide large amounts of water ’salt and other impurities. At the same time, ships are subject to trim ’ rolling ’vibrations and shocks. Affected by these factors, the solar panels will be polluted, shade, corroded and abased, resulting in the optical attenuation and surface damage of the cover glass of solar cell. (Gangopadhyay U & Dhungel S K, 2007) Therefore, in order to ensure the optical reliability and working reliability of the PV array, the glass cover over the solar panels is required for coating. In order to ensure the optical reliability and reliability of the PV array, and the anti-corrosion treatment should also be carried out on PV system stent.

# CHAPTER6

# RESPONDING COUNTERMEASURES TO THE APPLICATION OF SOLAR PV SYSTEM ON LARGE OCEAN-GOING SHIPS

Although the application of solar PV system on large ocean-going ships has significance on ship's energy-saving and emission reduction, this technology bring out a series of challenges to maritime safety management. Thus in order to ensure the safety of life at sea, Maritime safety administration (MSA) authorities should do some research on this new technology and make corresponding countermeasures in advance.

## 6.1 Legal dilemma confronted by application solar PV system on large ocean-going ships.

### 6.1.1 The lack of international conventions and the absence of uniform international standards

Until now, there are no special international regulations, specifications and instruments on the design and construction of applying solar PV system on board ships. The solar PV ship is a new technology, and the related national laws and regulations are usually obscure and lack of operability. Besides, one more issue on this technology is the absence of uniform international standards. Different countries in the world have different standards on solar energy and eventually built different solar ships. In addition, the different standards make different criterion on ship survey and certificates issue, resulting in a series of controversy correspondingly. On the one hand, it is harmful to shipbuilding. Due to the absence of uniform standard, the low quality products can flow into market resulting economic loss of honest shipbuilders. On the other hand, the absence is also bad for supervision of MSA when the staff carry out inspections. Because it is difficult to judge which country's standard is more reasonable and scientific without the same criterion.

### 6.1.2 The related regulations and law on solar power ships in China

There are only a part of normative documents available for the design and construction for solar ships in China.

(1) Ship's Electric Propulsion System Technical Conditions in China (GB/T 13030-91)

This regulation was proposed by China Shipping Industry Corporation (CSIC) in 1990 and was approved in 1991 by the National Bureau of Technical Supervision of China (NBTS). The detailed technical requirement for building, test, running and maintaining for marine electric propulsion system is regulated by this standard and is applied on solar power ships.

(2) General Specification for Sea-use Solar Cell Modules (GB/T 14008-92)

This standard was formulated by the Solar Photovoltaic Standardization Committee of China in 1992. This specification provides provisions and requirements of solar modules on the following aspects: the product classification, test methods, technical requirement and inspection rules. The solar products used on board ships should follow the requirement of this specification.

(3) The Appendix 2 of "Rules for Construction and Classification of High Speed Craft": Guidelines for Direct Calculation of Hull Structure Strength of High Speed Craft.

This guideline mainly presented the catamaran's structural strength calculation method and was formulated by China Classification Society in 2006, there is a specific part concerning the construction requirements and technical specifications on the catamaran solar power ship.

### 6.1.3 Feasible solutions to the legal dilemma

The main purpose of applying solar PV system is energy-saving and environmental protection, so administration authorities should support the development of this technology. From the national level, each country should establish policies, laws and regulations for this technology applied on ships. From the international level, United Nations Educational Scientific and Culture Organization (UNESCO) should pay more attention to solar PV technology, strengthen international cooperation and promote technical exchange; IMO should pay more attention to the application of this technology to ships, establish corresponding guidelines and regulations to promote its development.

## 6.2 Special trainings of crews working on solar ships

### 6.2.1 Reasons for special training

Crew's training has significant impact on ship's safety. General training provides seafarers with the basic knowledge and skills required to work on board while special training gives seafarers practical and specific skills working on special ships, such as oil tankers and chemical tankers. Similar to oil tankers or chemical tankers, ships with solar PV system is also a special ship type, especially for ships used solar energy as ship's propulsion. Thus special training should also be carried out for crew who service on ships with solar PV device. However, there is no such a special training standard currently. More seriously, some ships with solar energy as power of propulsion are manned with crew for internal combustion engine ships. Therefore, in order to ensure the safety of ship, current seafarer training system should be improved.

### 6.2.2 Feasible solutions to the issue of special crew training

For the ship with solar energy as propulsion power, special training is requisite for all engineers and officers working on it. Certification exams and special assessments should be taken before they get on board. The working principle, the operating procedures and the maintenance method of PV system should be taught for engineers by professionals in class. The maneuver ability of such ships is also different from conventional ships. Thus the officers or pilots should have enough understanding of the technical features by training. For ships which are converted years after built, engineers should update their knowledge by training in which relevant knowledge and skills can be provided. Besides, the demand of electrician or electrical engineers becomes more urgent. Years of practice has proved that the position of the electricians cannot be canceled on board, especially for ships with solar PV system. A general engineer is unable to solve problems on both electrical and mechanical aspects. Comparing with normal generators, the solar PV system requires crew with professional knowledge and skills. As the current generated by PV cells is direct, which is different from AC generated by ships generators, a special training or updating training is essential for the professional electrical engineers.

### 6.3 Survey of PV system applied on board ships

Besides the normal classification and statutory surveys, special surveys should also be conducted on ships with solar PV system. Take “COSCO STAR” for example, the hull structure and dynamical system is different from the conventional ship and the ship stability as well as the gross tonnage is also changed after the solar PV system is installed. At the end 11 ship certificates were re-audited by China Classification Society. Therefore, in order to ensure the sea worthiness of such ships, MSA should conduct special inspections and surveys before issuing the ship’s safety certificate while classification societies should provide surveyors with sufficient professional knowledge and skills to survey these ships. However, currently there are no survey standards for solar energy ships. So it is urgent to establish a new survey system or incorporate the inspect of solar ship into the existing one. IMO should also establish related instructions or guidelines for classification societies.

### 6.4 Inspection of solar power ships

It is true that the MSA is till lack of enough capacity to conduct both FSC and PSC on solar ship. With the development of PV technology, there will be growing numbers of large ocean-going ships applied with solar PV systems. To ensure the safety of shipping, the following two aspects should be considered in advance ：Firstly, establishing reasonable inspection guidelines for PV products used on board ships. The suitable inspection guideline is essential for both PSC and FSC. However, the guidelines should refer to the standards given by IMO or International Electrical Commission (IEC), which in turn makes it more urgent that IMO should establish guidelines or specification for solar PV products applied on ships. Secondly, knowledge updating of PSCO and FSCO. Port State Control Officers and Flag Stat Control Officers are familiar with conventional ships, but most PSCO and FSCO are not familiar with this new technology. Thus the knowledge updating is essential for those who take the inspection. Knowledge should be taught to them just like special training does for crew.

# CHAPTER7

## CONCLUSION

As a green and in inexhaustible energy, solar energy will gain wider application in the future. Although at present the solar PV generation technology is mostly used on small ships, it will gradually be used on large ocean-going ship as the following issues were solved: low conversation efficiency of solar cells, limited arrangement area for solar arrays and low weight-to-power ratios of batteries. Admittedly, the application of solar PV system on board ships triggers many challenges to MSA. However, with the training being conducted and the establishment of relevant laws, conventions, regulations and specifications, these challenges will be overcome in the end. Hopefully, the solar PV generation technology would be more widely used on ships and make the shipping more cost-effective and more environmental friendly.

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